

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
17 October 2002 (17.10.2002)

PCT

(10) International Publication Number
WO 02/081909 A2

(51) International Patent Classification⁷:

F03G

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SB, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZM, ZW.

(21) International Application Number: PCT/US02/11007

(22) International Filing Date: 4 April 2002 (04.04.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/281,864 4 April 2001 (04.04.2001) US

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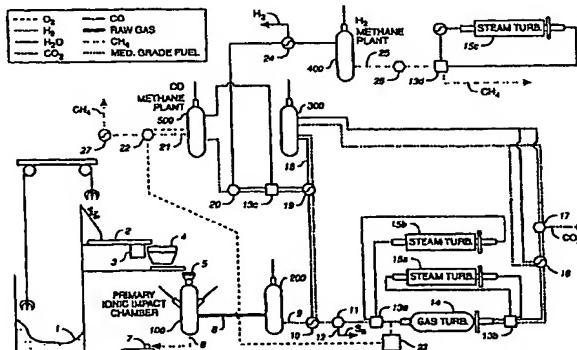
(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: SOLID-WASTE ENERGY PLANT USING CATALYTIC IONIC-IMPACT DECOMPOSITION AND COMBUSTION PRODUCT REGENERATION



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(57) Abstract: A solid-waste conversion plant produces useful products and electrical energy in a closed system with zero emission of pollutants into the atmosphere. The plant is characterized by catalytic ionic-impact chambers (100, 200, 300, 400, 500) having a pair of electrodes that establish an electric arc. The electric arc breaks down solid waste molecules into a plasma of atomic constituents which exothermically recombine into simple molecules upon leaving the plasma. A primary chamber (100) converts carbon-based waste into solidifiable metal and glassy slag (7) extractable from the bottom of the chamber (100), and into gas (8) containing CO, H₂, and CH₄. A second chamber (200) contains high carbon waste input that is converted by the arc into incandescent coke, which converts CO₂ and H₂O in the gas from the first chamber into more CO, H₂ and CH₄, thereby forming a fuel gas (9). The fuel gas is combusted in gas turbine generators (14) to produce electricity for operating the electric arcs, plus a sellable surplus. The flue gases are regenerated in a third chamber (300) substantially like the second. At least some of the CO₂, H₂ and CH₄, may be extracted (17, 24, 27, 13d) from the plant for commercial sale.

-1-

Description

SOLID-WASTE ENERGY PLANT USING
CATALYTIC IONIC-IMPACT DECOMPOSITION
5 AND COMBUSTION PRODUCT REGENERATION

TECHNICAL FIELD

The invention relates to solid waste conversion
10 and energy production facilities, and in particular to power plants that are specially adapted for conversion of solid municipal and industrial waste into carbonaceous fuel and other marketable products and the use of such fuel in electricity generation. Such plants that have
15 zero or substantially reduced airborne pollution emissions are especially relevant.

BACKGROUND ART

Approximately ninety percent of the carbon-based waste produced in industrial societies is interred in land fills. Disposal of municipal and industrial solid waste has become a major issue due to space limitations for land fills. Land fill interment adds to environmental pollution and the energy contained therein is lost to human use. Industrial use of this wasted energy could significantly impact dependency on fossil fuels. Some waste materials, such as human medical waste, pose public health problems that require their destruction, e.g. by incineration, rather than disposal
20 in a land fill. Gasification of municipal, industrial and medical solid waste material by conventional means, such as incineration and pyrolysis, results in airborne emissions -- primarily nitrous and sulfurous gases (NO_x and SO_x), ash and other suspended particulate matter (PM),
25 and partially-burned hydrocarbons (HCs), with the mix and amounts of the different pollutants depending on the type of plant, the particular solid waste input into the plant, and the efficiency with which it consumes the
30
35

-2-

solid waste material. Such pollution has frequently resulted in local opposition and site location zoning problems for new waste incineration or pyrolysis facilities.

5 Approximately sixty percent of the electricity generated in the United States comes from the burning of coal and oil, while another ten percent is produced from burning natural gas. The burning of these fossil fuels releases carbonaceous (CO, HCs) and nitrous gases (NO, NO₂, NO₃, HNO₂, etc.), as well as sulfur dioxide (SO₂), 10 into the atmosphere, contributing to urban smog, although usually at lower levels than the aforementioned conventional solid waste burning plants. The operations of many fossil fuel electrical generating plants, 15 particularly coal burning plants, are restricted to a certain number of hours per day, because full-time operation would otherwise exceed legal pollution limits.

20 Conventional industrial furnaces, used to produce heat and electrical power for manufacturing processes, also emit flue gases into the atmosphere.

25 A major source of air pollution is nitrogen oxides (NO, NO₂, NO₃, HNO₂, etc.). Ambient air is composed of 79 percent nitrogen, and nitrogen oxides are commonly contained in flue gases resulting from open-air combustion processes. For readily combustible fuels, like natural gas, the formation of nitrogen oxides can be reduced, but not eliminated entirely, by using a lean fuel-to-air ratio. Flue scrubbers can be incorporated into plants to remove nitrogen oxides (as well as SO₂ and 30 other pollutants) from the exhaust prior to release into the environment.

35 In U.S. Patent No. 6,066,825, Titus et al. describe a system for generating electricity from the conversion of solid waste material into a gaseous fuel followed by combustion in a turbine or other generator. The conversion of the waste material involves a combination of an electric arc plasma furnace and a joule-heated melter. The plasma furnace is operated such

-3-

that fast pyrolysis of the waste material occurs, creating a mixture of mostly CO and H₂, with small amounts of CH₄ and other light HCs, and a small amount of CO₂. Non-gaseous components of the pyrolysis product are
5 vitrified by the joule-heated melter into a highly stable glass product that can be disposed of safely or used commercially. The fuel gases are preferably combusted using a lean fuel-air mix in a steam-injected compressor-gas turbine or in an internal combustion engine, so as to
10 produce electricity.

An object of the present invention is to provide an improved waste treatment and power production facility capable of converting solid waste materials to useful energy (heat and electricity) and marketable
15 commercial products with zero air pollution emissions, the operation of which is largely or entirely self-powered.

DISCLOSURE OF THE INVENTION

20 The object has been met by a solid-waste energy plant containing a series of catalytic ionic-impact chambers to convert carbon-based waste material into fuel gas and also to regenerate the flue gases that are the product of combustion in turbine generators. The plant
25 operates largely as a closed system to eliminate emission of flue gases into the atmosphere. Excess regenerated fuel and other useful waste conversion products can be separated and sold commercially.

The plant receives carbon-based waste material
30 in a first catalytic ionic-impact chamber, which uses an electric arc to subject the waste material to homolytic bond cleavage, breaking the molecular bonds and leaving a plasma gas, which then recombines into simple molecules of H₂, CH₄, CO, CO₂, S₂, H₂S, etc. The exact mix of
35 resultant gases depends upon the composition of the waste material input into the chamber and choice of operating parameters, but it is mostly H₂ and CO, and is a medium grade fuel gas. The sulfurous components, if present,

-4-

are removed by a scrubber and the elemental sulfur sold commercially, as is any glassy or metallic slag material recovered from the bottom of the first chamber. The scrubbed gas can be further energized by passage through
5 a second ionic-impact chamber filled with incandescent coke (derived from high-carbon waste, such as shredded rubber tires). There, H₂O is converted to H₂ and CO,
10 while CO₂ is converted to CO, through reaction with the carbon in the incandescent carbonaceous materials. After combustion of the energized fuel gas in a turbine, which generates electricity for the plant, the flue products of CO₂ and H₂O are cycled to another ionic-impact chamber, also filled with incandescent coke, for regeneration back
15 into medium grade fuel gas of H₂ and CO. Excess gases may be converted in yet other ionic-impact chambers to H₂ and CH₄ and sold commercially. Excess CO₂ could also be sold.

In this way, solid waste material that would otherwise be disposed in landfills is converted into fuel for energy generation. High-carbon wastes, like rubber
20 tires, which are normally difficult to convert directly into gaseous fuel in arc plasma chambers because of their relatively low oxygen content, are used for flue gas regeneration and thereby effectively converted into energized fuel gas. The energized fuel operates turbine
25 generators for supplying the electric power for the electric arcs that heat the reaction chambers, as well as for sale of the excess electricity generated. The zero-emission closed system eliminates air pollution, as all products are extracted for commercial sale.
30

BRIEF DESCRIPTION OF THE DRAWING

Fig. 1 is a schematic plan view of the solid-waste energy plant of the present invention.

35 BEST MODE FOR CARRYING OUT THE INVENTION

With reference to Fig. 1, the illustrated solid-waste energy plant recycles solid-waste by converting it into usable energy and commercial

-5-

byproducts. The plant operates in five main stages. Three of the stages involve the use of catalytic ionic-impact chambers. Another stage uses the synthetic fuel gases produced by the ionic-impact chambers for the
5 conventional generation of electricity in turbine generators, but with the flue gases being recycled instead of being released into the atmosphere. Yet another stage involves the conventional scrubbing and cleaning of gases using standard off-the-shelf
10 technology.

Stage 1: Waste Dissociation

Solid waste 1 is collected, shredded by conventional methods, and fed into the first of the
15 catalytic ionic-impact chambers 100. Solid waste 1 may include industrial, medical, agricultural or municipal waste, as well as sewer sludge. The undifferentiated waste that is collected is preferably sorted to some extent to remove obviously non-carboniferous matter, such as bulk glass and aluminum recyclables. For example, a magnetic separator 3 might be used to extract ferrous metals. The sorted waste would then be largely carbon-based matter before being fed into a shredder 4.
20 Shredded waste is continuously fed, e.g., via conveyor belts 2 and feed hoppers and auger feed 5, into the primary ionic-impact chamber 100. Inside this chamber 100, the waste is reduced by an electric arc to a plasma, the gaseous product is drawn off at the top 8 of the chamber, while molten metals and vitrified slag are drawn off at the bottom 6 of the chamber and sulfur condensing from the gas is drawn off at the scrubber 11. This nongaseous product 7 can be sold as base metal for further refining, as sulfur for use in the chemical industries, and as industrial sand for use in roadbeds
30 and the like.
35

Within the first chamber 100, an electric arc is emitted between carbon rod electrodes. Within the arc that extends between the tips of the rods, carbon-based

-6-

material is hammered apart or broken down first into smaller molecular components and ultimately into its atomic constituents, forming a plasma. Plasma temperatures created within the electric arc typically exceed 5600° C. As the excited atoms and ions leave the plasma, they recombine into simple molecules of H₂, CH₄, CO, CO₂, S₂, H₂S, etc. (Most of the gaseous sulfur then condenses out as the gas cools away from the electric arc and plasma as it passes through scrubber 11.) This electric arc molecular milling process releases energy in the form of heat as the large molecules from higher states of chemical equilibrium (primarily solids and liquids) are broken down to simple gas molecules with more tightly bound configurations and lower state of equilibrium, after being sufficiently excited and completely decomposed. All of the carbon-based material is converted in this way. Hazardous and semi-hazardous medical or industrial materials are rendered harmless in this first stage chamber.

This ionic impact or hammering process differs from incineration in which the large molecules of matter in the solid waste are burned or combusted in the presence of ambient air and applied heat (flame). This process also differs from conventional pyrolysis or gasification techniques in which application of external heat to the waste in an oxygen starved environment causes the molecules in the carbon-based matter to break down. Instead, the arcing electricity and resultant ionic impacts in the plasma cause the bond cleaving and molecular breakdown, and the heat is a byproduct of the breakdown and subsequent recombinations into smaller more tightly bound molecules. The generated heat from this chamber or from the hot gases drawn from the chamber can be used to drive steam turbines through heat exchange.

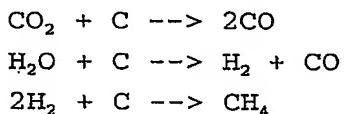
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Stage 2: Carbon Energizing of the Gas

Gaseous products 8 from the first ionic-impact chamber 100 are directed into one or more second

-7-

catalytic ionic-impact chambers 200, which are filled with incandescent coke in the form of high-carbon-based waste, such as shredded rubber tires. The number of second chambers 200 will vary depending on such variables
5 as the number of gas turbines 14 in service, which dictates the gas volume required. As in the first stage chamber (or chambers) 100, the high-carbon-based waste material is subjected to the ionic-impact process, i.e.
10 electric arcing between electrodes, which reduces the carbon-based molecules to a plasma 'gas'. Again, the chemical equilibrium change creates heat. The raw incoming gas 8 ducted from the first chamber 100 into the second chamber 200 mixes with the plasma gas (largely carbon atoms and ions), with further catalytic ionic-
15 impact processing and molecular state changes occurring.



20 These reactions are endothermic and add energy to the molecular gas products, with the energy supplied by the electric arc that excites the high carbon waste to a plasma and by the consequent recombination heat from the breakdown and equilibrium change. As a result of the
25 reactions in these second chambers 200, much of the CO₂ and H₂O from the waste decomposition process becomes reconstituted as CO, CH₄, and H₂. Gas exit temperatures typically exceed 1900° C. The gas 9 emitted from the
30 second chambers 200 is a mole percent mixture (dependent on the solid waste composition) of approximately 60% H₂, 36% CO, and 4% CH₄. This is a medium grade fuel usable by gas turbines 14.

At this point, recycled flue gases 18 that have
35 been regenerated (stage 4 below) enter the fuel stream via a valve 10. All of these fuel gases are scrubbed 11 to remove any residual sulfur compounds (especially SO_x), sodium, or nitrogen compounds. These extracted chemicals

-8-

12 can be sold commercially, for example as sulfuric acid, nitric acid, and nitrate fertilizers, or if not available in sufficient quantity, can be neutralized.

5 Stage 3: Electricity Generation

The heat from the catalytic ionic-impact chambers 100, 200 and 300 and the synthetic fuel gas 9 and 18 produced by them can be used to generate electricity using conventional turbine generating means 14, 15a and 15b, with the difference that resulting combustion products will not be released into the atmosphere, but instead be recycled and regenerated. The heat from the ionic-impact chambers 100, 200, 300, etc., and from the hot output gases 9 and 18 drawn from those chambers can be used with heat exchangers 13a and a closed-loop water-to-steam system to drive one or more steam turbines 15a and 15b. The fuel gases 9 and 18 can be burned in gas-driven turbines 14. The hot flue gases from the fuel combustion in the gas turbines 14 can also be used with heat exchangers 13b to drive one or more steam turbines 15a and 15b. All of the turbines 14, 15a and 15b generate electricity for internal plant use and for commercial sale. Gas and steam turbine electrical generation is well known in the art.

It is noted that the decomposition of solid waste 1 is unlikely to provide all of the oxygen needed for complete combustion of all of the fuel gases burned in the plant, except possibly where a large portion of the fuel is drawn off 24 and 27 in stage 4 described below and sold commercially. The oxygen available from the decomposition and energizing is already bound up in the CO in the fuel gas. (Otherwise, if the waste material contained enough oxygen, the recombination products from the ionic-impact chambers would already be almost entirely CO₂ and H₂O, and then no further energy could be extracted from the product gases via combustion.) Combustion of the CO, H₂ and CH₄ in the fuel gas requires an additional source of oxygen. One source

-9-

of additional oxygen is available from the methane plant 22 described below for stage 4. Also, a conventional source of additional oxygen for combustion of the fuel gas in the conventional gas turbine(s) is ambient air 5 (about 20% oxygen). A lean fuel-air mix could be used in the turbines to minimize nitrogen oxide formation. Any nitrogen oxides that are formed would not be released into the atmosphere because the flue gases are recycled. The nitrogen oxides could then be removed by scrubbers. 10 Alternatively, some of the heat generated in the plant could be used to run an oxygen plant 23 for nitrogen separation and removal from the ambient air (e.g., by liquefaction) prior to intake of the oxygen into the turbines. This would eliminate nitrogen oxide formation 15 altogether, and the separated liquid nitrogen is a commercial product that could be sold or make ammonia to be used in the manufacture of urea that is used as an ingredient in fertilizer.

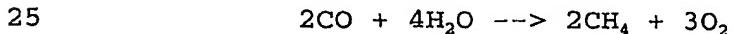
20 Stage 4: Flue Gas Regeneration

As noted above, the flue gases produced in the turbine(s) are captured and channeled back into one or more reprocessing chambers 300. (The number of chambers required to optimize gas masses depends on the mix of waste consumed, the number of generators used, and the desired output of commercial gases.) Again, these 25 chambers 300 are catalytic ionic-impact chambers filled with high carbon waste. The flue gases are regenerated in these chambers 300, i.e. energized with more carbon as 30 in stage 2, to create more medium grade fuel gas 18 of CO and H₂, with some CH₄. (Refer again to the reactions set forth in the above description of stage 2.) After regeneration the fuel gas 18 can be returned 10 to the fuel stream 9, scrubbed 11 and sent again through the gas 35 turbine(s) 14.

Alternatively, some or all of the flue gas components (e.g., CO₂) and regenerated gas components (especially the CH₄ and H₂) can be cooled, separated,

-10-

scrubbed and sold as commercial gas. Flue gases may be routed by a valve 16 to a conventional scrubber-separator 17, which extracts some of the CO₂ for industrial use. The remaining CO₂ and water vapor may be returned to the flue stream for regeneration in the aforementioned ionic-impact chambers 300. Regenerated gas 18 may be passed through a valve 19, cooled in a heat exchanger 13c, and sent to a hydrogen separator 20, where H₂ is captured and passed through another valve 24 for commercial sale. Or the captured H₂ may be converted to CH₄ (2H₂ + C --> CH₄) in yet another catalytic ionic-impact chamber 400 filled with incandescent coke (high carbon waste), passed through a scrubber 26, cooled in a heat exchanger 13d and sold commercially. The steam from the heat exchanger 13d may drive a steam turbine 15c. (The heat from any of the heat exchangers 13a-13d may be used to generate steam to drive steam turbines 15a-15c and generate electricity, with the water and steam circulating in a closed loop.) Returning to the regenerated gas 18, after separation 20 of the hydrogen, the remaining CO plus steam from a heat exchanger 13c may be introduced into a methane conversion chamber 500, which is yet another catalytic ionic-impact chamber. There the reaction is:



The reaction is endothermic and the energy is provided by both the electric arc and the heat contained in the steam. The recombining of carbon monoxide with water vapor to produce methane and oxygen (a kind of reverse combustion) occurs at elevated temperatures. The resulting methane and oxygen are then separated 22. The methane may be captured at a valve 27 and sold to a natural gas distributor. The oxygen derived from the methane conversion process may be directed from the separator 22 to an oxygen plant 23 where it can be used to enhance combustion of the fuel gases 9 and 18 in the gas turbines 14. This results in a cleaner burn with

-11-

substantially reduced nitrogen oxide production.

Alternatively, the oxygen might be captured and sold.

Stage 5: Scrubbing of Gases

5 Conventional technology is used to clean the gases at various points (e.g. 11 and 26) in the plant. Impurities removed from the gas may constitute commercially sellable products. If not, they can be neutralized and safely disposed. Sludge from any of the
10 scrubbers might be drawn off and reintroduced into the first stage chamber 100, where it can be reprocessed into vitreous slag 7.

15 CO₂, a product of combustion, can be converted into dry ice and sold. Or it might be sequestered using technologies currently being developed or to make urea. Nitrogen oxides (NO_x) can be converted 11 into nitric acid or nitrate fertilizers and sold commercially. Likewise, sulfur oxides can be converted 11 into sulfuric acid or sulfate compounds and sold commercially.

20 H₂ and CH₄ gases created in stage 4 can be extracted from the gas mix in a conventional gas separation process (e.g., at 20 and 22), and cleaned for commercial sale.

25 Conclusion

By carrying out these five stages in a plant like that shown and described, solid waste material can be converted to usable products, including fuel gas.
30 Electrical power generation can be produced cleanly in a closed system characterized by zero pollution emissions into the atmosphere. The key to this waste conversion is the breakdown of solid waste molecules to simpler gases by means of catalytic ionic-impact chambers 100, 200, 300, 400 and 500 using an electric arc and resulting hot plasma ions to cause homolytic bond cleavage followed by exothermic recombination. Even high carbon wastes can be converted in such chambers by chemical reactions between the gases and incandescent carbon to energize and

-12-

regenerate more fuel gas. Reaction heat is recovered by heat exchangers and the steam used to generate electricity. A very clean and efficient waste conversion and power generation plant is the result.

-13-

Claims

1. A solid-waste conversion plant, comprising:
 - 5 a first ionic-impact chamber having a pair of electrodes for establishing an electric arc therebetween, carbon-based solid waste introduced into said chamber being molecularly broken down by homolytic bond cleavage by said electric arc and forming an ionic plasma of atomic constituents of said solid waste, said
 - 10 constituents exothermically recombining into simple gaseous molecules including CO and H₂ upon leaving said ionic plasma in said electric arc with release of heat, other constituents forming a solidifiable material extractable from the bottom of said chamber;
 - 15 a second ionic-impact chamber having a pair of electrodes for establishing an electric arc therebetween, said second chamber filled with high carbon waste which is broken down by said electric arc to an incandescent coke, gaseous molecules from said first chamber, including CO₂, H₂O and H₂, being energized by said coke and converted in said chamber to CO, more H₂ and CH₄, thereby forming a fuel gas;
 - 20 at least one gas turbine generator combusting said fuel gas to generate electricity sufficient at least to run said electric arcs in said chambers; and
 - 25 a third ionic-impact chamber forming a flue gas regenerator, the ionic-impact chamber connected to a flue outlet of the gas turbine generator to receive combustion products therefrom for regeneration in said chamber, the third ionic-impact chamber having a pair of electrodes for establishing an electric arc therebetween, and being filled with high carbon waste which is broken down by said electric arc to an incandescent coke through which the combustion products pass and are converted into a fuel gas containing CO and H₂;

-14-

wherein said conversion plant forms a closed system with recycled flue gases and zero gas emissions into the atmosphere, excess fuel gas produced by the solid waste breakdown and conversion in said chambers
5 being extractable from said plant.

2. The conversion plant of claim 1 wherein said high carbon waste comprises shredded rubber tires.
10

3. The conversion plant of claim 1 further comprising at least one closed-loop water/steam heat exchanger system drawing heat from the hot gases exiting one or more of
15 the chambers, said closed-loop water/steam heat exchanger system driving one or more steam turbine generators.

4. The conversion plant of claim 1 further comprising at
20 least one conventional scrubber system connected to remove impurities from said gases exiting one or more of the chambers.

25 5. The conversion plant of claim 1 wherein the solidifiable material extractable from the bottom of the first ionic-impact chamber comprises at least one of molten metals and vitreous slag.

30 6. The conversion plant of claim 1 wherein a conventional CO₂ separator is located in the path of flue gases from said gas turbine generator, whereby at least some CO₂ in the flue gases can be extracted.
35

-15-

7. The conversion plant of claim 1 wherein at least some regenerated fuel gas output from said third chamber is recirculated to fuel gas input into at least one gas turbine generator.

5

8. The conversion plant of claim 1 wherein at least some regenerated fuel gas output from said third chamber is drawn off to a hydrogen separator, wherein H₂ in said fuel gas is removed therefrom.

9. The conversion plant of claim 8 further comprising a fourth ionic-impact chamber in a path to receive the removed H₂, the fourth chamber having a pair of electrodes for establishing an electric arc therebetween, the fourth chamber filled with high carbon waste which is broken down by said electric arc to an incandescent coke, wherein the H₂ is converted in said fourth chamber by said incandescent coke to CH₄.

10. The conversion plant of claim 9 wherein heat from hot CH₄ exiting said fourth chamber drives a steam turbine generator via a closed-loop water/steam heat exchanger system cooling the CH₄.

11. The conversion plant of claim 8 wherein steam and CO remaining after said H₂ has been removed from said fuel gas is received in a fifth ionic-impact chamber having a pair of electrodes establishing an electric arc therebetween, wherein said steam and said CO are converted to CH₄ and O₂ in said fifth chamber.

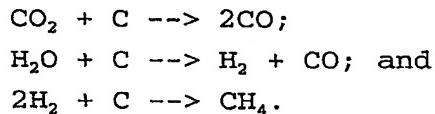
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-16-

12. The conversion plant of claim 12 further comprising an O₂ separator removing said O₂ from the CH₄, said O₂ being supplied to at least one gas turbine generator.

5

13. The conversion plant of claim 1 wherein said electric arcs in said second and third ionic-impact chambers and heat from incoming gases facilitate at least the following three endothermic chemical reactions with
10 the incandescent coke:



15

14. A method of converting carbon-based solid waste to usable products and energy, comprising:
introducing said carbon-based solid waste into
a closed-system conversion plant containing at least
20 first, second and third ionic-impact chambers, each
ionic-impact chamber having a pair electrodes therein
establishing an electric arc therebetween, said second
and third chambers being filled with high carbon waste
which is broken down by said electric arc into
25 incandescent coke, the carbon-based solid waste
introduced into said first chamber being molecularly
broken down by homolytic bond cleavage by said electric
arc and forming an ionic plasma composed of atomic
constituents of said solid waste, said constituents
30 exothermically recombining into simple gaseous molecules
including CO and H₂ upon leaving said ionic plasma in said
electric arc with release of heat, other constituents
forming a solidifiable material extractable from the
bottom of said chamber;

-17-

energizing said gaseous molecules from said first chamber by means of passage of said gaseous molecules through said incandescent coke in said second chamber, whereby CO₂, H₂O and H₂ in the gas is converted
5 in the second chamber to CO, more H₂ and CH₄, thereby forming a fuel gas;

combusting at said fuel gas to generate electricity sufficient at least to power said electric arcs in said chambers;

10 regenerating flue gas products of the combustion in the third chamber, whereby CO₂ and H₂O in said flue gas is converted to CO, H₂ and CH₄ by passage of said flue gas through the incandescent coke in said third chamber; and

15 separately extracting at least some of the CO₂, H₂ and CH₄ from the closed-system conversion plant.

15. The method of claim 14 further comprising using heat
20 generated by said chambers to drive steam turbine generators by means of a closed-loop water/steam heat exchanger system cooling hot gases exiting said chambers.

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